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STANFORD, CALIFORNIA 94305



**FINANCIAL ASSESSMENT OF THE
SPACE OPERATIONS CENTER
AS A PRIVATE BUSINESS VENTURE**

By

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ABSTRACT

The possibility of private financing and operation of the Space Operations Center (SOC) is considered as an alternative to SOC development by the government. A hypothetical revenue model for SOC services is constructed and is compared with NASA estimates of SOC development and operating costs. A present-value analysis based on a 1985-2000 investment horizon shows a potential for substantial profit in a private SOC venture, although the possibility of large losses is not discounted. Present-value estimates range from \$8.6 billion down to a low of minus \$3.3 billion.

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James M. Beggs, Executive Chairman**

I. INTRODUCTION

The idea of establishing a permanently-manned space station in Earth-orbit is not a new one. Scientific work on this subject dates back to the early 1900s, and studies have identified many possible design configurations for such a facility. The National Aeronautics and Space Administration (NASA) recently formed an office to study the multi-purpose Space Operations Center (SOC), which now appears to be a likely candidate for a manned U.S. space station.

Early studies of the economics of the SOC have raised an interesting question: could a facility such as the SOC be built and operated for profit by a private organization? Government and industry are likely to find this question increasingly relevant as man's role in space expands. As the commercialization of space communications is followed by the opening up of markets for space processing, space energy systems, and space habitation, the opportunities for profitable endeavors in space will multiply. A space operations base would play a pivotal role in this entire industrialization process, and private ownership of a space station would be consistent with American ideals and historical precedent. As this paper will point out, such an enterprise might also be financially attractive.

II. THE SOC MISSION MODEL

The major obstacles to the private financing of a SOC are similar to those for other proposed space projects: a large up-front investment, long lead-time, and high risk. Unlike programs such as the satellite power system, however, the SOC would provide a wide variety of basic services, most of which are essential for the realization of widely-accepted near-term space goals. The versatility of the SOC would guarantee an active market for SOC services, and would help to insure financial success in such operations.

By the early 1990s a SOC could be involved in dozens of independent space operations. These can be divided into three categories: basic operations, military operations, and specialized operations. Basic operations are those whose profitability are easiest to predict, and which would be most likely to provide economic stability during the critical early years of SOC operations. Basic operations consist of launch services (from low-Earth to geosynchronous orbit) for communications satellites, and space science services. Military operations are potentially as valuable as basic operations, but cannot be assessed without the involvement of high-level defense authorities. Military operations could include the launch,

storage, repair, and protection of military satellites, Earth and space observations, and possibly even space construction. Whether the military would be willing to have these services provided by a private organization is questionable, but such cooperation between the military and industry would not be unprecedented. Finally, specialized SOC operations would offer the potential for the long-term growth of SOC activities, although the SOC could be involved in such functions by the early 1990s. Specialized operations include launch services for non-communications payloads, satellite servicing, and, most importantly, materials processing in space (MPS). MPS alone could provide several billion dollars of SOC revenue annually by the end of this century. Other specialized operations such as space construction and the processing of non-terrestrial materials are also compatible with, if not dependent upon a SOC, but will not be considered in this financial assessment.

III. BASIC OPERATIONS

One of the major functions of a Space Operation Center would be the delivery of communications satellites to geosynchronous orbit. The SOC would be located in low Earth-orbit (LEO), within range of the Space Shuttle. Communications satellites could be launched from Earth via the Shuttle, and then transferred at the SOC to reusable, chemical-propulsion orbital transfer vehicles (OTVs). The OTVs would have a payload capacity of about 12,000 pounds, and could deliver as many as four satellites at a time to geosynchronous orbit. It is likely that two OTVs could be berthed at the SOC at all times.

The profitability of launching communications satellites via the SOC would depend upon a number of factors. These include, primarily, the demand for space communications and the cost of operating the SOC OTVs. Since we have had considerable experience with space communications and various types of launch vehicles, it is not impossible to evaluate these conditions. Demand for the launch of communications satellites is expected to increase dramatically by the 1990s, with over 150 communications satellites expected to be in orbit by the year 2000. Many of these satellites will be very large in comparison with today's communications satellites, and the SOC would be particularly valuable for the launch of these large payloads. Table 1 shows projections of the demand for launches of various sizes of communications satellites over the next twenty years. To support this level of traffic, approximately 100 OTV flights would be required during the 1990s. (ref. 1).

The costs of utilizing SOC (or space-based) OTVs for delivery of these satellites can be broken down into three components: development costs, unit costs, and operating costs. Development costs (DDT&E) for SOC launch services consist of the cost of developing the OTV launch system, which can be estimated at about \$1 billion. The unit cost (cost per OTV) could range from \$35 million to \$110 million per vehicle. Operating costs include the

Table 1

Satellite Launch and Shuttle Flight Requirements (Communications Satellites)

Year	Satellites in Orbit Size*			Satellites Launched Size*			Number of Shuttle Flights
	Total	A	B	C	A	B	
1982	38	23	14	1	8	4	1
83	47	28	18	1	10	7	0
84	57	32	22	3	9	8	2
85	66	37	25	4	11	7	1
86	75	40	29	6	10	9	3
87	95	44	32	9	11	8	5
88	92	47	35	10	11	9	3
89	101	50	38	13	11	9	5
1990	108	51	41	16	10	10	6
91	116	53	44	19	11	10	6
92	123	54	47	22	10	11	7
93	127	55	48	24	10	9	6
94	134	55	51	28	9	11	9
95	139	54	53	32	8	11	9
96	144	54	55	35	9	11	9
97	146	53	55	38	8	9	9
98	149	50	57	42	5	10	11
99	151	50	57	44	8	8	9
2000	153	48	58	47	6	9	11
2001	156	48	58	50	8	8	11
2002	158	47	58	53	7	8	12
Total					190	186	135
Average Per Year					9.05	8.86	6.43
							275.50
							13.12

*A = Delta equivalent, B = Atlas Centaur equivalent, C = IUS equivalent

From: "Forecast of Space Shuttle Requirements for Launch of Commercial Communications Satellites,"
Future Systems Inc., Sept. 6, 1977.

cost of periodically refurbishing the OTVs (estimated at \$20 million to \$50 million every ten flights, plus \$50 million for transportation of the OTV to Earth and back to the SOC each time), the cost of delivering communications payloads to the SOC via the Shuttle (\$12 million per OTV flight), and, most importantly, the cost of delivering fuel for the OTVs to the SOC (about \$42 million per OTV mission). These costs are summarized in Table 2; the high cost estimates have been used for conservatism. The total cost per OTV flight, including amortization of development costs, is slightly over \$81 million. (ref. 2).

The best way to estimate the profitability of SOC communications launch services is to compare the cost of utilizing the space-based OTVs with other possible launch methods. The cost "savings," or the difference between the cost of using the SOC OTVs and of the other launch vehicles, represents an upper bound on the profitability of the SOC launch system. The SOC OTVs could be compared with today's expendable launch vehicles (Delta, Titan, etc.), but since the expendables are almost certain to be obsolete by the 1990s, this would not be a valid comparison. One exception might be Europe's Ariane expendable launch vehicle, which is expected to provide NASA's Space Transportation System with stiff competition for launch services for certain types of payloads. When reliable data about the costs and capabilities of Ariane's future systems (Ariane II, III, and IV) become available, it could influence the results of this assessment.

Another possibility is to compare SOC OTV costs with the expected costs of the Shuttle upper-stage boosters, the SSUS-D, SSUS-A, and IUS. The upper-stage costs are shown in Table 3. When compared with the SSUS and IUS, the space-based OTV shows a dramatic cost advantage, with average annual savings of over \$500 million during the 1990s. Figure 1 shows OTV savings as a function of the demand for the launch of communications satellites. Even if demand varies from current projections, the space-based OTV is likely to have a significant cost advantage over the Shuttle upper-stages.

However, the Shuttle upper-stages may also be obsolete by the 1990s, even though they have never been used to date. If the upper-stages were the only alternative to the SOC OTVs, a company operating a SOC could conceivably earn annual profits of close to a half a billion dollars on communications satellite launch services. It is not difficult, however, to envision other launch systems capable of competing with the SOC OTVs. The closest competitor appears to be a single-stage Earth-based OTV, which would be launched directly from the Space Shuttle and which would resemble the proposed Shuttle-Centaur launch system. It too would be likely to have tremendous cost advantages over the Shuttle upper-stages, as illustrated in Table 4. (Table 4 also includes data on a 2-stage Earth-based OTV system which would not depend upon the Space Shuttle. This system is not competitive with the other options.)

Given optimistic cost-estimates for the single-stage Earth-based system (a worst-case condition for the SOC, again a

**COSTS OF ALTERNATIVES TO SHUTTLE UPPER STAGES
(100 MISSIONS)**

<u>EARTH-BASED OTV (1-STAGE)</u>			
DDT&E	\$1000 M		
UNIT COST (100)	2000 M		
	<u>\$3000 M</u>		
/100		\$30.0 M/FLT.	
PAYLOAD & FUEL COST			
1 SHUTTLE LAUNCH	\$60.0 M/FLT.		
			<u>\$90 M/FLT</u>

<u>EARTH-BASED OTV (2-STAGE)</u>			
DDT&E	\$1000 M		
UNIT COST			
Lower Stage (6)	660 M		
Upper Stage (100)	3000 M		
REFURBISHMENTS (9)	<u>450 M</u>		
	\$5110 M		
/100		\$51.1 M/FLT.	
PAYLOAD & FUEL COST			
2 SHUTTLE LAUNCHES	\$120 M/FLT.		
			<u>\$171.1 M/FLT.</u>

<u>SPACE (SOC)-BASED OTV</u>			
DDT&E	\$1000 M		
UNIT COST (6)	660 M		
REFURBISHMENTS	<u>450 M</u>		
	\$2110 M		
/100		\$21.1 M/FLT.	
FUEL COST (PER FLT.)			
42,000 LB @ \$1000/LB			
=	\$42.0 M/FLT.		
OTV TRANSPORTATION			
(TO SOC FOR REFURBS)			
=	\$6.0 M/FLT.		
COST OF PAYLOAD TO SOC			
(VIA SHUTTLE)			
=	<u>\$12 M/FLT.</u>		
			\$81.1 M/FLT.

Reference: Johnson Space Center (NASA) SOC Program Office; in-house estimates

TABLE 3

COSTS OF SHUTTLE UPPER-STAGES

<u>TRANSPORTATION (STS) COSTS</u>		Payload Dependent Charges
<u>SSUS-D</u>		
Length: 7.75 ft.	Load factor: $7.75/60 = .13$	
Weight: 6,528 lb.	" : $6528/65,000 = .10$ - Charge factor = $.13/.75 = .173$;	Charge = $\$9.4M + 1.2M = \underline{\$10.6M}$
<u>SSUS-A</u>		
Length: 7.5 ft.	Load factor: $7.5/60 = .125$	
Weight: 12,600 lb.	" : $12,600/65,000 = .194$ - Charge factor = $.194/.75 = .258$;	Charge = $\$14M + 3.9M = \underline{\$17.9M}$
<u>IUS</u>		
Length: 16.8 ft.	Load factor: $16.8/60 = .28$	
Weight: 41,500 lb.	" : $41,500/65,000 = .638$ - Charge factor = $.638/.75 = .851$;	Charge = $\$46.3M + 10M = \underline{\$56.3M}$

UPPER-STAGE UNIT COSTS

SSUS-D - \$6.6M
 SSUS-A - 8.8M
 IUS - 40.0M

UPPER-STAGE TOTAL COSTS

SSUS-D - $\$10.6M + 6.6M = \underline{\$17.2M}$
 SSUS-A - $\$17.9M + 40.0M = \underline{\$26.7M}$
 IUS - $\$56.3M + 40.0M = \underline{\$96.3M}$

Reference: STS Reimbursement Guide, NASA JSC-11802 May 1980

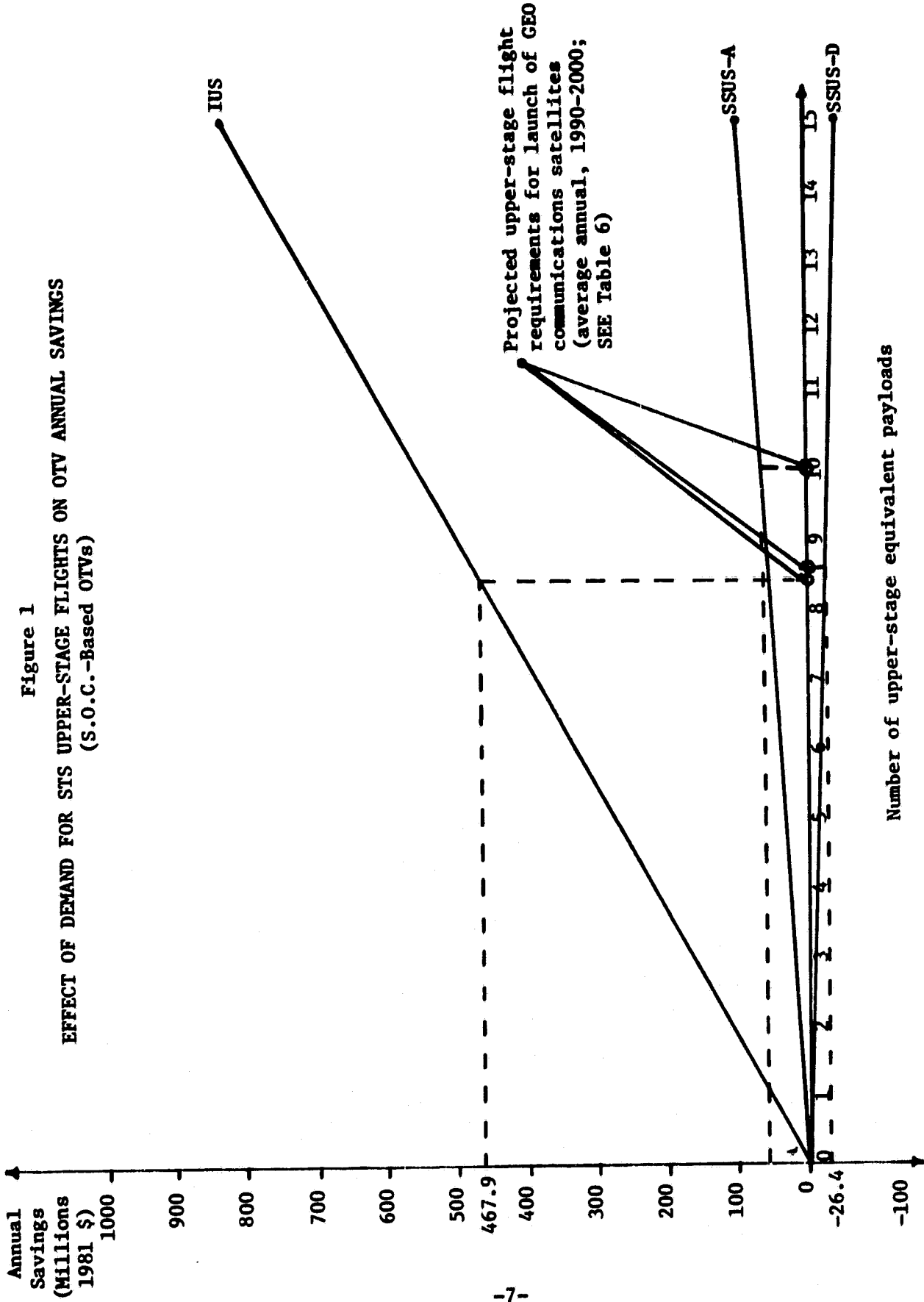


TABLE 4

SHUTTLE UPPER-STAGE/OTV COST COMPARISON

OPTION PAYLOAD	SHUTTLE UPPER- STAGES	1-STAGE EARTH- BASED OTV	2-STAGE EARTH- BASED OTV	SPACE- BASED OTV
DELTA	17.2	22.5	42.8	20.3
ATLAS	26.7	22.5	42.8	20.3
IUS	96.3	45.0	85.6	40.6

SINGLE PAYLOAD
COST TO G.E.O

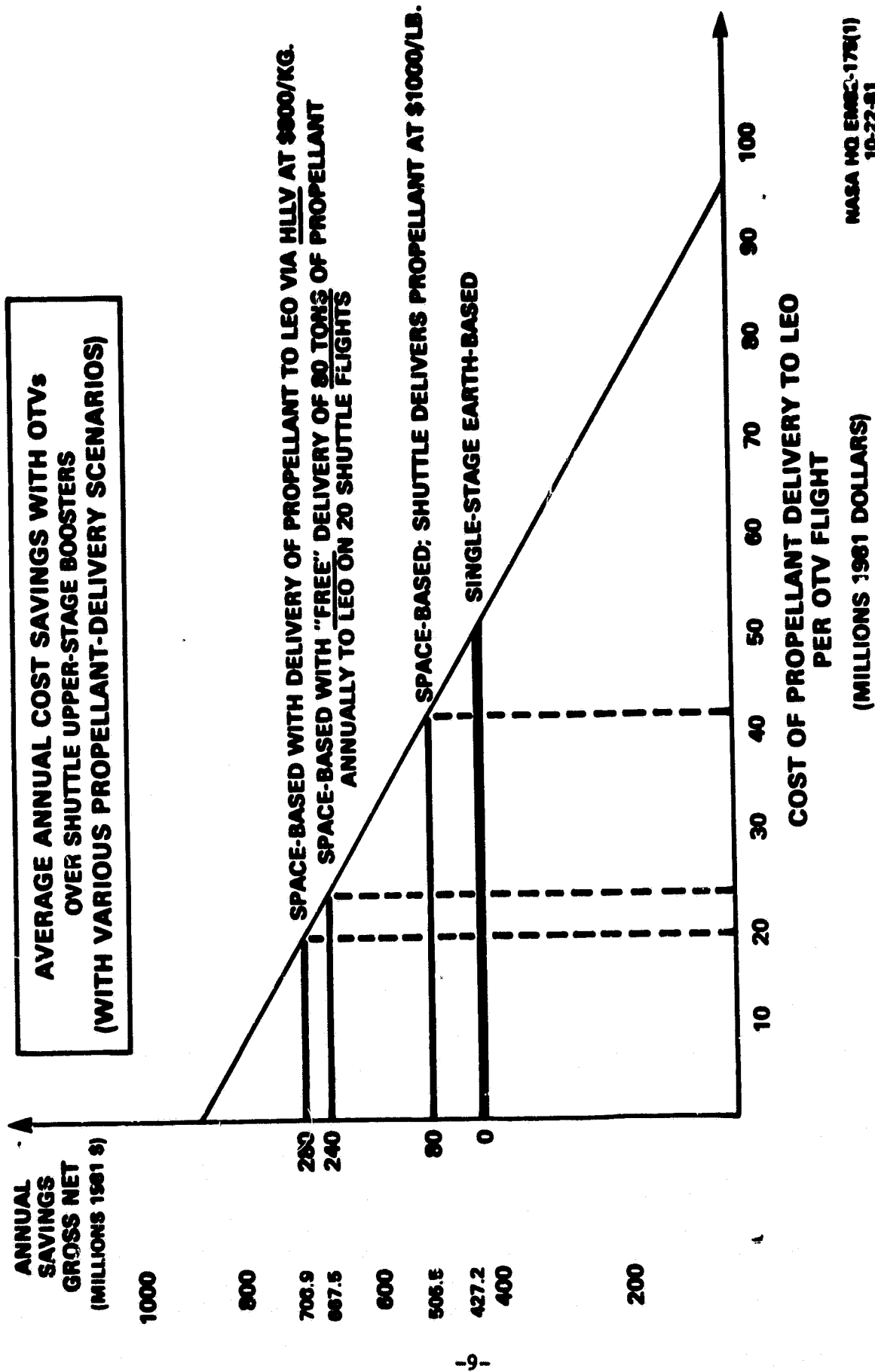
(MILLIONS 1981 DOLLARS)

OPTION PAYLOAD	ANNUAL FLIGHTS REQUIRED	1-STAGE EARTH- BASED OTV	2-STAGE EARTH- BASED OTV	SPACE- BASED OTV
DELTA	8.5	(5.3)	(217.6)	(26.4)
ATLAS	10.0	42.0	(161.0)	64.0
IUS	8.4	430.9	89.9	467.9
TOTAL SAVINGS (LOSS)		427.8	(288.7)	505.5

AVERAGE ANNUAL COST
SAVINGS (LOSSES)—
USING OTVs, RELATIVE
TO SHUTTLE UPPER-
STAGE COSTS

(MILLIONS 1981 DOLLARS)

FIGURE 2



conservative assumption), the profit potential of the space-based OTV system is reduced from over \$500 million per year to under \$80 million. Figure 2 summarizes the cost savings (i.e. maximum profit potential) of the space-based OTV in comparison with the Shuttle upper-stages and the Earth-based OTV. Figure 2 also illustrates the significance of the propellant delivery costs to the SOC. If the cost of delivering fuel to low Earth-orbit could be reduced from \$42 million to some lower cost, the SOC OTVs would look much more attractive. For example, if 80 tons of propellant could be delivered to the SOC for "free" each year by draining excess fuel from Shuttle external tanks, or by using liquid oxygen as "ballast" in the Orbiter cargo bay, then the profitability of the SOC OTV system could be increased by a factor of three. Another possibility shown in Figure 2 is delivery of OTV fuel to the SOC by a heavy-lift launch vehicle (HLLV), a Shuttle-derived "tanker" which reduces lift costs from Earth by about 60%. This would provide an even greater cost advantage than the Shuttle fuel "scavenging" scenario. A more ambitious alternative is to process liquid oxygen from lunar ore, which could reduce propellant delivery costs to \$5 million per OTV flight or less. Since this is a highly speculative option it is not included in this analysis, but it is conceivable that SOC launch operations could provide sufficient economic justification for the establishment of a lunar mining operation aimed at liquid oxygen production.

Using the SOC as a base for the launch of communications satellites could generate annual profits of \$80 million to \$290 million or more by the 1990s. Although other SOC operations would ultimately be expected to have even greater profit potential, the SOC OTVs could provide financial stability and a guaranteed income as the other SOC operations develop. Another basic operation which could be presumed to have profit potential during early SOC operations is space science services. The SOC could play a vital role in the advancement of scientific research in space, particularly in the area of life sciences. Unfortunately, much of the SOC's value to space science is qualitative, and is difficult to evaluate. For example, how much will it be worth to have the ability to conduct long-duration studies of living systems on the SOC? How is this value translated into SOC profit potential? These questions are further complicated by the fact that the government would probably be a major consumer of SOC space science services.

We can, however, develop a simplified model of SOC space science operations, and obtain a rough preliminary estimate of the dollar value of such services. Consider, for example, the option of making the European Spacelab a permanent element of the SOC design. Aside from increasing the maximum duration for Spacelab missions from one week to several months or years (a tremendous benefit in itself), this set-up would have an obvious economic advantage: the Spacelab module would not have to be launched into space more than once, saving tens of millions of dollars in transportation costs on Spacelab missions every year. A SOC-Spacelab mission would require the launch only of

experiment racks and support personnel, which would require at most one-third of a Shuttle flight. Integrating the experiment racks into the Spacelab in space would be more complex than doing so on the ground, but would cost only a tiny fraction of the \$36 million which would be saved on every Spacelab mission by freeing two-thirds of a Shuttle flight. Assuming 4-8 Spacelab missions per year during the 1990s, savings on Spacelab transportation costs could range from \$144 million to \$288 million per year.

In addition to transportation, there could be large savings on dully SOC-Spacelab operations. The cost of operating the Spacelab at the SOC would entail a relatively small marginal increase in basic SOC operating costs, and could therefore cost \$200,000 to \$500,000 per day less than operating the Spacelab in the Shuttle cargo bay. If it is assumed that the Spacelab would be in use at the SOC for at least 2 to 4 months per year, then total savings on Spacelab transportation and operations could range from \$160 million to \$350 million per year. Using the SOC as a permanent base for the Spacelab would also represent a far more efficient utilization of the Space Transportation System than if the Shuttle had to be used for every day of Spacelab operations.

Many space science experiments will also have the potential to lead to commercial applications of space technology. The SOC-Spacelab would have an advantage over the Shuttle-Spacelab in its provision of facilities for expansion to commercial-scale space operations. For example, materials processing in space experiments during the 1990s are likely to result in the discovery of pharmaceuticals, electronics materials, and other products for which zero-gravity space processing would be economically advantageous. The SOC would have the space, energy, manpower, and mission duration capabilities for commercial-scale processing of many products that the Shuttle would not be able to provide. The SOC would also serve as a base for space construction, and could ultimately evolve into a full-scale "space factory." Revenue from basic operations would not be dependent upon such long-term developments, but the basic operations could eventually lead to a SOC monopoly of space manufacturing capabilities, which could be of enormous value.

IV. MILITARY OPERATIONS

During the 1990s and beyond, military uses of space are likely to expand as rapidly, if not faster, than civilian space applications. It is almost certain that a manned station in low Earth-orbit such as the SOC would be valuable, if not essential, for national defense. This could turn out to be a positive influence on the commercial viability of a SOC venture, but the financial picture of SOC military operations needs much clarification. Assuming that the military would be interested in using a privately-operated space station, it is still very difficult to assess the value of such operations to the SOC ownership. This is primarily because of the secrecy involved in

the planning of future military space activities.

Launch of military payloads to geosynchronous orbit is a possible SOC service which could rival the launch of civilian communications satellites in financial importance. The Department of Defense (DOD) could also be presumed to have an interest in various types of space science activities, particularly those involving human beings in space for extended periods. Various reports have indicated that the military also has a profound interest in a manned "battle station" in space. (ref. 3). Its functions would include storage, servicing, and protection of military satellites; construction of large space systems such as power systems, particle-beam weapons, and energy shields; and manned coordination of military space activities. For these reasons it could be assumed that SOC revenue from military space operations could be as great as revenue from SOC basic operations, but for the purposes of this analysis it is also assumed that military SOC applications could be non-existent.

Even if the military were not willing or able to use a private SOC, however, its interest in space could indirectly help to make development of a private space station possible. The military could, for example, develop its own space station, and subsequently make the results of its DDT&E work available to the private sector. This would greatly reduce the cost of building a separate private space station, since as much as 85% of the cost of a facility such as the SOC would fall into the general category of research and development. One way in which the military and the private sector could share SOC costs would be for the DOD to pay a firm to design and develop a military space station, and for the firm to then build its own space station on the basis of the same R&D work. The second, commercial space station could perhaps be financed from profits made on development of the first (DOD) space facility. A private organization with an interest in establishing a SOC could pursue negotiations with military officials to assess the possible role of the DOD in such cooperative activities. A financial picture of the SOC would be incomplete without thorough consideration of such alternatives.

V. SPECIALIZED OPERATIONS

Whereas basic operations and perhaps also military operations could provide a reliable source of income during the early years of SOC activity, there is a much broader range of specialized operations upon which the financial prospects of the SOC would ultimately depend. These specialized operations would make the SOC not only a focal point for space communications activities, but also for the development of space processing, space energy systems, and, in the long term, space habitation. It requires a bit of imagination to envision all of these as thriving industries, but the same was true of the now explosive space communications industry two decades ago. Not only would the SOC

have applications in all of these fields, but it could indeed be absolutely essential for the development of these industries. The owners of a SOC would have great influence over the development of these industries, as well as the financial benefits which could be realized through such pioneering endeavors.

As space activities continue to expand, demand for assorted launch services should increase. In addition to the basic operation of launching communications satellites, a SOC could be involved in the transfer of non-communications payloads to higher orbits. These could include remote-sensing and other science and applications payloads, as well as experimental structures, such as prototype satellite power systems. There would probably be a relatively small number of such payloads, since low-Earth orbit would suffice in many cases, but non-communications payloads could probably increase usage of SOC OTVs by 5-10% over that required for communications satellite launch services. This could represent an additional \$4 million to \$28 million per year in SOC profits.

Satellite servicing is another specialized SOC operation with a measurable profit potential. Despite the fact that communications satellites have relatively short operating lives (8-10 years), repairing, refurbishing, and upgrading these satellites in space could become an important SOC function. Estimates of the value of such services run as high as 40% of the total value of the satellite serviced, which is frequently in the tens of millions of dollars. Assuming a rather conservative profit of \$2 million to \$5 million per satellite serviced on ten to twenty such jobs per year, the SOC profit potential from satellite servicing can be calculated at \$20 million to \$100 million per year.

The most important specialized operation for a Space Operations Center, however, would almost certainly be materials processing in space. The profit potential from space processing during the 1990s and beyond is enormous, and, unlike other SOC operations, MPS has virtually unlimited growth potential. Unofficial industry projections of the gross annual sales of space-processed materials range as high as \$50 billion by the end of this century. It can be safely stated that MPS is likely to be a key to the financial success of any SOC venture.

Unfortunately, it is impossible to verify estimates of the value of space processing. We are only beginning to understand the effects of zero-gravity on materials, and years of expensive research will be required before commercially viable space processing operations can be identified. NASA and industry have identified certain types of pharmaceutical products and electronics materials which may be significantly cheaper to produce in space than on Earth, and it is widely agreed that space processing will eventually become a thriving industry. But nobody knows exactly how or when.

A small number of companies have invested significant resources in MPS research, and some expect to begin commercial

space processing activities within this decade. Because of the high stakes involved, however, firms engaged in MPS are generally reluctant to publicize the results of their scientific and marketing research. McDonnell-Douglas Corp. (MDAC) has probably done the most to demonstrate the profit potential of space processing, but much of the company's work is shrouded in proprietary secrecy. MDAC has teamed with Johnson & Johnson to produce pharmaceuticals in space, and will begin flying experiments on the Space Shuttle as early as the summer of 1982. To date, tens of millions of dollars have been committed to this project by these two companies and by NASA (with whom a Joint-Endeavor Agreement has been signed), but it will still be several years before the commercial viability of these space processing operations can be proven. It may very well be worth the wait; annual sales of pharmaceutical products which are strong candidates for space processing are in the billions of dollars, and it can be safely assumed that MDAC is aiming for a significant share of this market.

Similarly, there are a number of electronics materials which have strong MPS potential. Space-processing of high-purity gallium-arsenide (GaAs) could revolutionize the electronics industry, and could generate a lively market for the product at several hundred thousand dollars per pound. In addition to pharmaceuticals and electronics materials, perfected glass products and exotic alloys might also be produced in space with results which could not be achieved on Earth, and at great profit.

There are few if any published estimates of the potential sales of space-manufactured products, but a survey of experts involved in MPS research would yield estimates of gross annual sales of space products in the range of \$200 million (in 1990) to \$50 billion (in 2000). This broad range of estimates illustrates the great degree of uncertainty with regard to the future of commercial MPS, but also demonstrates clearly a high level of confidence in the potential of space processing. For the purposes of this analysis this range can be narrowed to a more or less conservative \$1 billion to \$6 billion in gross annual sales as a 1990s average. If 20% of MPS sales could be allocated as "rent" to the SOC, then the SOC revenue potential from space processing would be in the range of \$200 million to \$1.2 billion per year by the mid-1990s.

Despite the uncertainties involved, it is evident that MPS could become the single most profitable SOC operation by the end of the 1990s. With continued growth in commercial space processing applications, the Space Operations Center could ultimately evolve primarily into a space factory, regularly shipping a wide variety of important medical and industrial products to Earth. Ground-based MPS research and small Shuttle experiments over the next several years should help to resolve the uncertainties involved in commercial space processing, and should also help to clarify the SOC financial picture.

VI. SOC REVENUE SUMMARY

The revenue projections for SOC operations are summarized in Table 5. Many possible SOC operations, such as space construction, are not included because of the difficulties involved in evaluating their profit potential. Those figures which are listed, however, are certainly open to debate as well. Many assumptions went into the formulation of these estimates, some of which are presented in Table 6, the SOC sensitivity analysis. Here the impact of a 50% change in the assumed or mid-range values of SOC operations and underlying assumptions are listed. For example, a 50% change in the mid-range value of military operations (\$315 million/year) results in a 10% change in SOC revenue. Similarly, a 50% change in the assumed demand for communications satellite launches (estimated to require 100 OTV flights from 1990 to 2000) causes a 6% change in SOC total revenue. The value of the sensitivity analysis is that it shows which SOC operations are most important to study in order to develop a more firm financial assessment of a SOC enterprise.

VII. SOC COSTS

Determining the cost of a Space Operations Center, although a formidable task in itself, is somewhat less risky than attempting to predict the profitability of SOC operations. Experience with Skylab, Spacelab, and previous generations of launch vehicles has provided a basic understanding of the major costs involved in the development and utilization of orbital space facilities, and the level of costs associated with the SOC would probably not be out of line with that of other large projects of the past. In fact, the SOC would probably cost only a small fraction of what Project Apollo cost (10-20%, at most), and less than half of what NASA has already invested in the Space Shuttle.

NASA is currently sponsoring in-depth studies of SOC costs, but fairly detailed first-order estimates have already been achieved. For a full "growth" SOC capable of the types of operations described in this paper, total development and production costs have been estimated at between \$5 billion and \$7 billion, with the actual hardware production costs accounting for only about \$1 billion of this total. The major contributors to SOC costs are DDT&E for the SOC habitat and service modules, systems testing and evaluation, and program support, which together comprise about half of the total. These cost estimates, however, are based on the assumption that NASA will be the builder and operator of the SOC. If the SOC were built by a private company, a total cost reduction of about one-third would not be an unreasonable expectation. Possibilities also exist for the reduction of SOC costs through simplification of the SOC design and utilization of existing hardware. A SOC fabricated from the Shuttle's external fuel tanks, for example, could greatly reduce the costs of the expensive habitat and service modules. Such possibilities need to be investigated thoroughly

TABLE S

SOC REVENUE SUMMARY

		LOW HIGH	
BASIC OPS.	COMMUNICATIONS SATELLITE LAUNCHES	COST ADVANTAGE OF SOC OTVs OVER BEST COMPETITOR, 1-STAGE EARTH-BASED OTV. VARIANCE DUE TO PROPELLANT COSTS.	\$ 80 280
	SPACE SCIENCE	\$36M COST SAVING PER "SPACELAB-EQUIVALENT" 1-WEEK MISSION, PLUS SAVINGS ON EXTRA-DAYS ON ORBIT. 4-8 WEEKS/YEAR.	160 350
		SUBTOTAL	240 630
SPECIAL OPS.	MILITARY OPERATIONS	COULD RANGE FROM 0 TO 100% X BASIC OPERATIONS	0 630
	NON-COMMUNICATIONS SATELLITE LAUNCHES	REVENUE IS 5-10% OF THAT DERIVED FROM LAUNCH OF COMMUNICATION SATS	4 28
	SATELLITE SERVICING	10-20 JOBS/YR @ \$2-5M EACH	20 100
	SPACE PROCESSING	20% OF GROSS ANNUAL SALES OF SPACE PRODUCTS	200 1200
		TOTAL	464 2588

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TABLE 6

SENSITIVITY ANALYSIS

	ASSUMED OR MID-RANGE VALUE	50% CHANGE	IMPACT OF 50% CHANGE ON SOC REVENUE
OPERATIONS			
1 COMMUNICATIONS SATELLITE LAUNCHES	\$180M	\$ 90M	6%
2 SPACE SCIENCE	\$255M	\$128M	8%
3 MILITARY OPERATIONS	\$315M	\$158M	10%
4 NON-COMMUNICATIONS SATELLITE LAUNCHES	\$ 16M	\$ 8M	½%
5 SATELLITE SERVICING	\$ 60M	\$ 30M	2%
6 SPACE PROCESSING	\$700M	\$350M	23%
ASSUMPTIONS			
1 COST PER FLIGHT—SOC OTVs	\$81.1M	\$40.6M	18%
COST PER FLIGHT—EARTH-BASED 1-STAGE OTV	\$ 90M	\$ 45M	19%
PROPELLANT DELIVERY COST/FLIGHT	\$30.7M	\$15.4M	9%
DEMAND FOR COMM. SAT. LAUNCHES (OTV FLTS REQ)	100	50	6%
2 SAVINGS ON SPACELAB TRANS. COSTS (PER MISSION)	\$ 36M	\$ 18 M	7%
NUMBER OF SPACELAB MISSIONS/YR.	6	3	7%
4 DEMAND FOR NON-COMM. SAT. LAUNCHES (PERCENT OF COMM. SATS.)	7.5%	3.8%	½%
5 NUMBER OF SATELLITE-SERVICE MISSIONS/YR. COST SAVINGS PER SERVICE	15	8	2%
6 GROSS ANNUAL SALES OF SPACE PRODUCTS	\$ 3.5M	\$ 1.8M	2%
PERCENT OF GROSS ANNUAL SALES AS SOC REVENUE	\$ 3.5B	\$ 1.8B	23%
	20%	10%	23%

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before a commitment is made to full development of any particular SOC design.

In addition to development and production costs, there would be basic costs involved in the support of the SOC crew and operations. A very rough estimate of these SOC operating costs is \$400 million to \$1 billion per year, which corresponds to approximately \$1 million to \$3 million per day. These costs would obviously increase with the expansion of SOC activities, but for the operations described in this paper over the given time period (1990-2000), it is unlikely that baseline operating costs would exceed \$1 billion per year. It should be emphasized, however, that these figures do not include variable costs associated with particular SOC operations, such as OTV costs (previously estimated at about \$81 million per OTV flight) and the costs associated with changing Spacelab equipment and personnel (\$20 million minimum per mission). These variable costs, however, are accounted for in the SOC revenue model; revenue from communications satellite launch services, for example, is calculated as the net difference between the variable cost associated with operation of the SOC OTVs, and the cost of launching communications payloads with other systems (e.g. Shuttle upper-stage boosters).

VIII. SOC PRESENT-VALUE ANALYSIS

One method which can be used to evaluate the attractiveness of the SOC as a private business venture is to perform a discounted present-value analysis. Figure 3 shows a "worst-case" present-value assessment for private SOC financing. Through a combination of tax credits, design modifications, and private-sector efficiency the actual undiscounted investment required is reduced from the estimated \$5-7 billion required for the NASA SOC (ref. 4) to \$4 billion. This is not an overly optimistic assumption. The analysis also assumes a real discount rate of 10%, a pessimistic assumption, and covers a five-year development period and the first decade of SOC operations. Based on the SOC revenue and cost models presented in this paper, three separate scenarios for the growth of SOC operating revenues are considered. On the high side, SOC profits begin at \$1 billion per year and grow at the rate of \$100 million per year. On the low side, the SOC starts off by losing \$200 million per year, and improves at the rate of \$50 million per year. In the median case, the SOC grows at a rate of \$75 million per year following initial annual earnings of \$400 million per year. The discounted present-value of the SOC enterprise, evaluated in the initial year, is measured on the vertical axis. The horizontal axis represents the duration of the investment horizon. If the median growth rate for SOC earnings were achieved, for example, then the estimated present-value of the first ten years of the enterprise would be about -\$1.6 billion. With the investment horizon extended to fifteen years (through the year 2000, in this example), the present-value would be approximately -\$0.25

FIGURE 3
PRESENT VALUE—WORST CASE
1985-2000

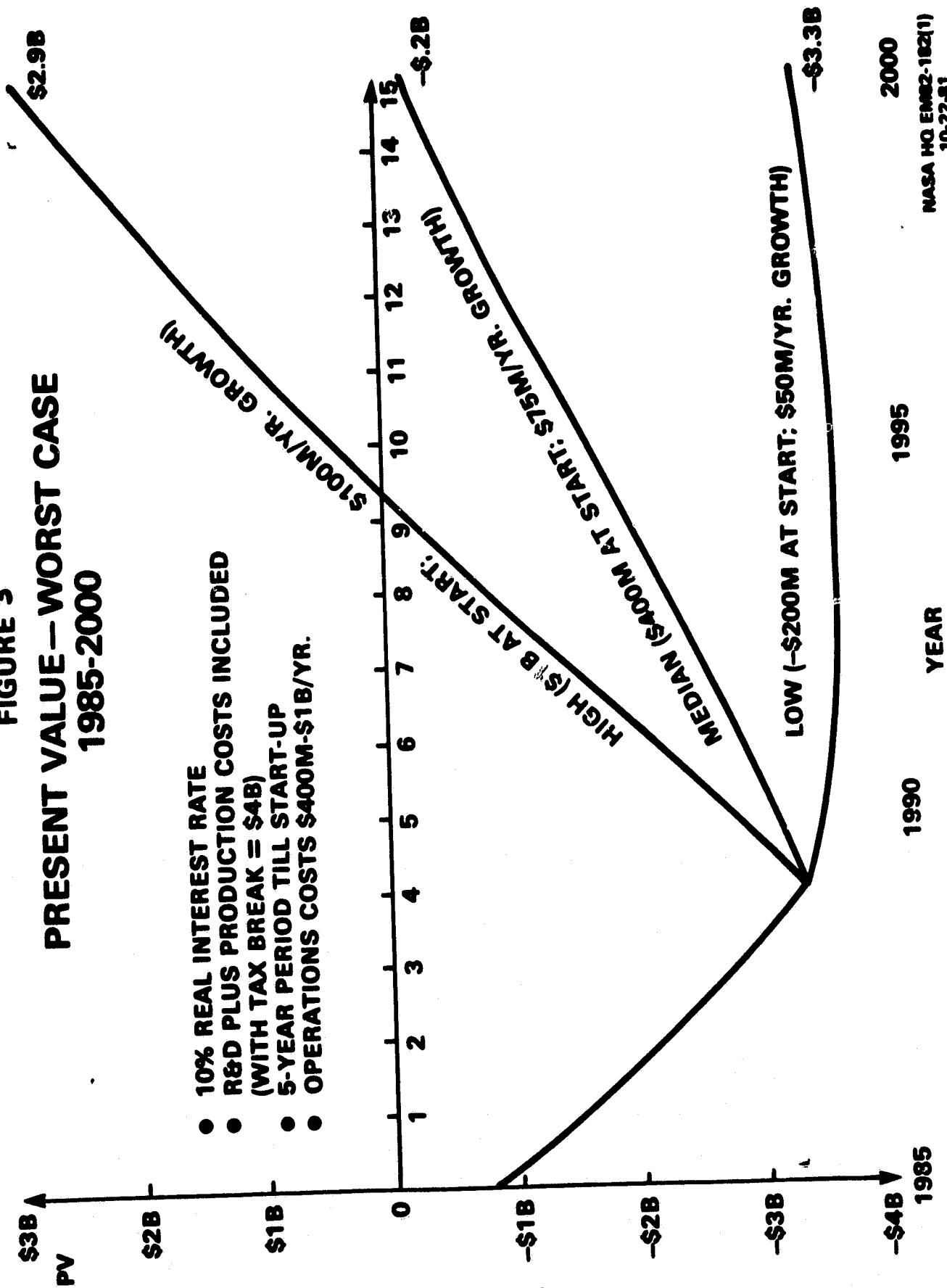
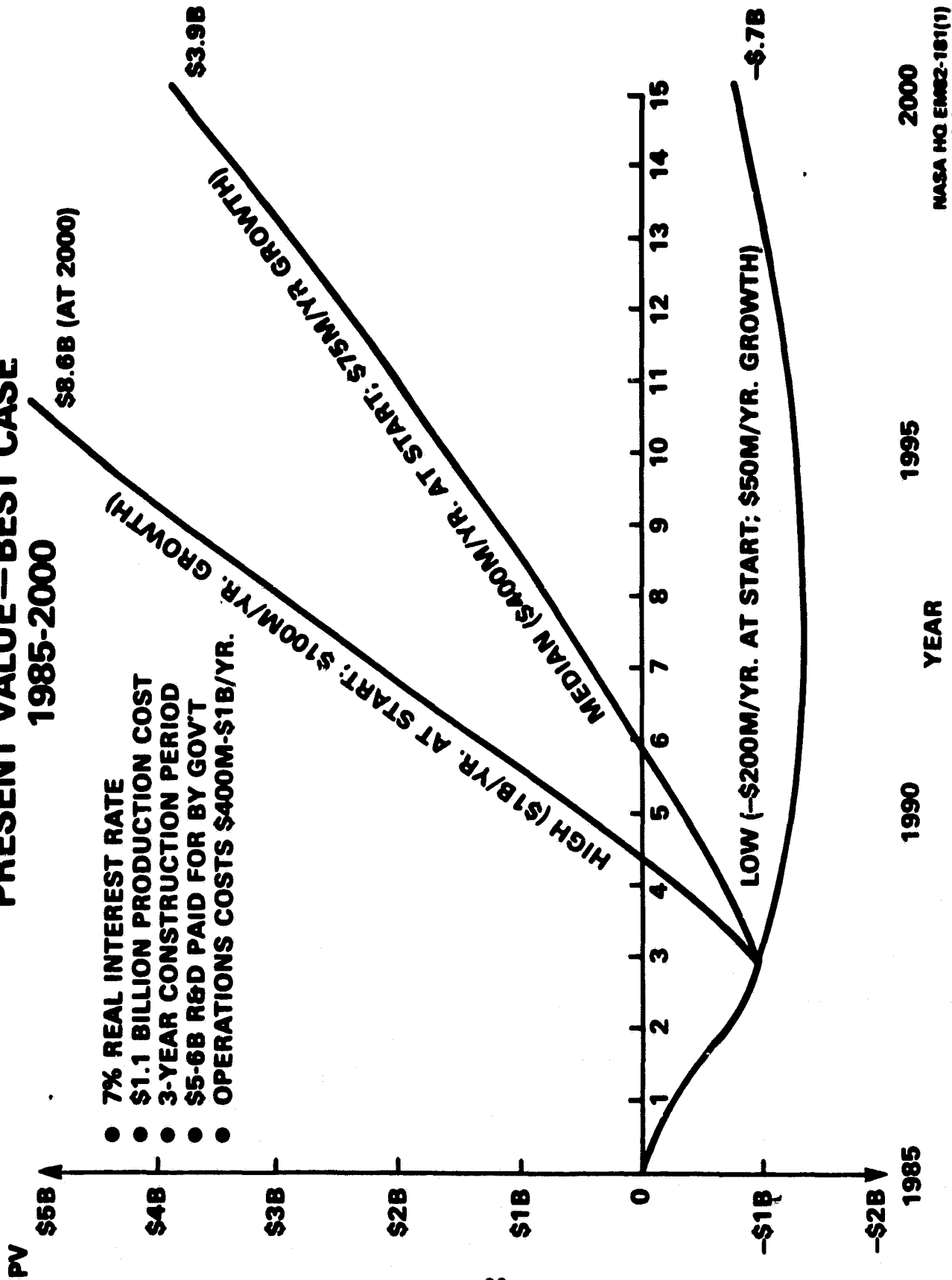


FIGURE 4
PRESENT VALUE—BEST CASE
1985-2000



billion. In this assessment the present-value of the SOC ranges from a loss of \$3.3 billion to a gain of \$2.9 billion. It should be noted that with an assumed 10% real discount rate, a significant risk expectation has been included in the analysis. The payback period in this worst case ranges from ten to twenty years.

Figure 4 shows a present-value analysis based on a set of more optimistic (and probably more likely) conditions. In this case it is assumed that through some type of joint private-public endeavor, the private investment is limited to the \$1.1 billion SOC production cost, and that SOC operations begin after a three-year investment period. The most likely means of achieving a SOC through this level of private financing would be for NASA or the DOD to fund SOC research and development, and for the private sector to become involved at the conclusion of such efforts, financing only the actual construction of the facility. There are, however, other possible means of reducing private outlays to the \$1 billion-range, including the earlier-mentioned options of tax credits and cost-saving design modifications. This "best-case" present-value scenario also assumes a real discount rate of 7%. The growth of SOC earnings is considered in the same three cases as the "worst-case" present-value analysis.

The results of the best-case present-value analysis are striking. Present-value ranges as high as \$8.6 billion, with payback periods as short as 5 years. Even the low-growth scenario results in a positive present-value if the investment horizon is extended slightly beyond the year 2000, and the median case yields a present-value of nearly \$4 billion. Why then, are private companies not stampeding to work with the government to develop a privately-operated multi-purpose Space Operations Center? There are three major reasons. First, these cost and revenue projections are all very "soft" and will require large expenditures of resources for confirmation. Second, the companies most qualified to undertake such a venture (such as aerospace and defense firms) have a vested interest in working through more traditional channels, and the concept of a privately-financed SOC will take some time to gain acceptance in the industry. Finally, companies (and non-aerospace firms in particular) tend to view all space projects as enormous, long-term, high risk investments, and if the SOC is an exception to this rule (which it may or may not be) it can be proven only at considerable expense.

The Space Operations Center is an exciting concept whose time may be coming. It may happen within this century, or it may take awhile longer to develop. While there is a broad spectrum of financing alternatives which might be applicable to the development of such a facility, the figures in this paper demonstrate that there is a chance that a SOC could be developed privately or semi-privately at a considerable profit, with the potential for particularly impressive long-term financial returns. Although this study is not in itself justification for such a venture, it does, in the author's opinion, present a set of fascinating business opportunities which merit careful consideration.

Appendix A - Decision Trees

The present value assessments performed in section VII considered only two of many possible financing alternatives for development of the Space Operations Center. SOC financing options can also be viewed in the context of a decision tree, which goes a step beyond calculation of discount rates in the evaluation of project risk. In the decision tree in Figure 5, the branches 1 through n emanating from the decision node D represent distinct SOC financing alternatives, and are hence "decision variables." Decision branch 1, for example, could represent a case in which the SOC is financed solely by private funds, which would be partially analagous to the "worst-case" present-value scenario in section VII (Figure 3). Decision n, at the other extreme, might represent a case in which the SOC is financed in full by the government.

Each financing alternative has associated with it a range of possible outcomes with regard to SOC value and earnings. Included among the outcomes for decision 1 might be the high, median, and low SOC earnings outcomes associated with the worst-case SOC financing scenario. In the SOC present-value analysis in this paper these outcomes were treated as discrete (distinct) growth rates for SOC earnings, each representing a particular present-value. The present-value associated with branch 1b in Figure 5, for example, would be the median growth scenario for the worst-case financing alternative, or -\$0.2 billion.

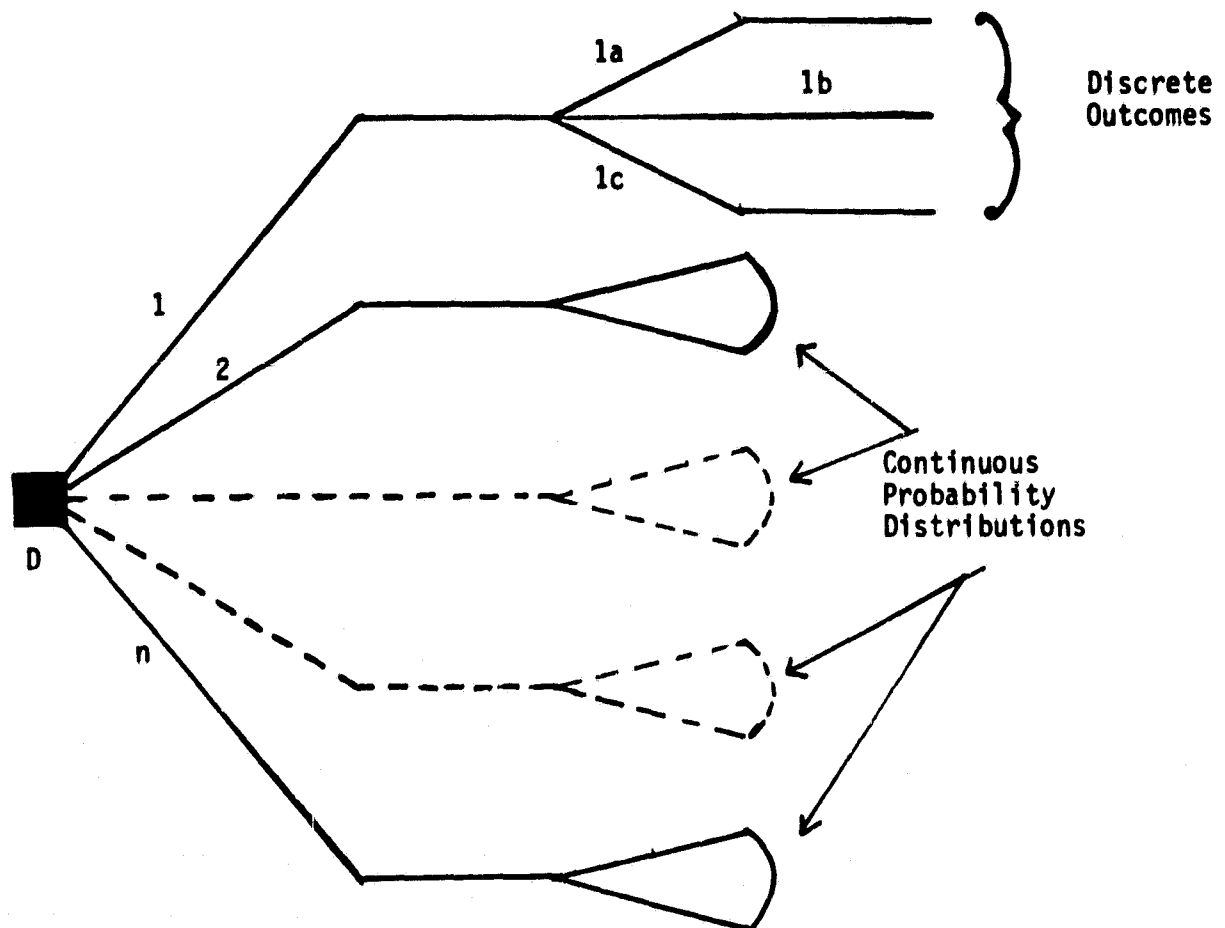
A vigorous comparative study of the values of various SOC financing options would have to attach many more than three possible value outcomes to each SOC financing alternative. In fact, discrete value outcomes might be discarded in favor of "continuous" distributions on earnings. For (undefined) financing alternative 2, for instance, present-value could perhaps range from -\$2 billion to \$2 billion, with an infinite number of possible value outcomes in between. To calculate the probability of attaining any particular present-value within this range would require knowledge of the "probability distribution" over SOC earnings for that financing option. A more thorough study of SOC financing alternatives would also have to better define SOC "present-value" and "earnings." In this paper, the value of the SOC was viewed primarily from the perspective of a private company engaged in a SOC enterprise, hence present-value was calculated in terms of dollar profit and was of course higher for the case in which much of the SOC financing was undertaken by the government. If instead total "social" costs and benefits were taken into account, the differences between the "best-" and "worst-case" present-value scenarios might not have been as great.

The final goal of the decision-tree analysis would be to associate with each SOC financing alternative a range of possible value outcomes and a probability distribution over each range. This would permit the calculation of the "expected value" of each

financing alternative, and the option with the greatest expected value could then be selected. As was just mentioned, however, judgment of the relative merits of each financing alternative would depend greatly on how SOC "value" is defined to begin with.

FIGURE 5

A Decision Tree for Various SOC Financing Alternatives



Appendix B - SOC Military Operations

In discussing SOC military operations, it is not the author's intent to advocate the militarization of space. The major purpose of this paper, in fact, is to explore possibilities for the rapid growth of peaceful applications of space technology. It should be recognized, however, that military uses of space can and have aided world stability by providing reliable communications systems, verification of compliance with arms control treaties, and the security which comes with knowing what other nations are doing militarily. It is hoped that it is these military operations which will be continued, rather than the development of space weapons systems which could undermine international stability and the balance of power. In order to prevent the latter possibility from becoming reality, it is the author's opinion that terrestrial and space arms control negotiations should be pursued vigorously, and that all civilian and military uses of the SOC and other space facilities should be carefully designed to enhance, rather than to weaken, the cause of world peace.

Notes

- 1. Future Systems Inc., "Forecast of Space Shuttle Requirements for Launch of Commercial Communications Satellites," September 6, 1977.**
- 2. NASA in-house estimates, Johnson Space Center, October 1981.**
- 3. New York Post, Monday October 5, 1981, page 2.**
- 4. Boeing Aerospace Company, "Space Operations Center - System Analysis: Final Briefing, June 25, 1981.**